MODIS and Landsat TM image fusion using the SIFuLAP method for mapping the Brazilian savannas (Cerrado)

Acerbi-Junior, F W ; Zurita-Milla, Raúl ; Wachowicz, M ; Clevers, J G P W ; Schaepman, Michael E

Abstract: The Cerrado is the second largest biome in Brazil, covering an area of about 2 million km2. However, recent estimates revealed that more than one third of the Cerrado was already converted into other land cover types. This paper presents a multi-temporal data fusion experiment where one Landsat TM image (30 m) was fused with a series of MODIS images (250-500 m). Moreover, a simplified data fusion method based on the Laplacian pyramid concept (SIFuLAP) is illustrated. The objective is to assess the ability of the fused images to reflect the seasonal patterns of the Cerrado. In order to do that, NDVI temporal profiles were derived from the fused images and subsequently compared with the ones that were obtained from the original MODIS images. In addition, the temporal fused products were used in an attempt to improve classification accuracy of the Cerrado. The results showed that the NDVI temporal profiles, derived from the fused images, were efficient to assess the seasonal behaviour of the Cerrado. Moreover, classification accuracy was improved using the temporal fused images as additional information into the classifier.

Originally published at:
Acerbi-Junior, F W; Zurita-Milla, Raúl; Wachowicz, M; Clevers, J G P W; Schaepman, Michael E (2005). MODIS and Landsat TM image fusion using the SIFuLAP method for mapping the Brazilian savannas (Cerrado). In: 25th Intl. EARSeL Symposium "Global Developments in Environmental Earth Observation from Space", Porto (P), 6 June 2005 - 11 June 2005. Millpress, 71-79.

MODIS and Landsat TM image fusion using the SIFuLAP method for mapping the Brazilian savannas (Cerrado)

F.W. Acerbi-Junior[1,2], R. Zurita Milla[1], M. Wachowicz[3], J.G.P.W. Clevers[1] & M.E. Schaepman[1]
[1] *Centre for Geo-Information (CGI), Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, The Netherlands. E-mail: Fausto.Acerbi@wur.nl*
[2] *Department of Forest Sciences, Federal University of Lavras, PO Box 3037, 37200-000 Lavras-MG, Brazil*
[3] *Centre for Geo-Information (CGI), Alterra, P.O. Box 47, 6700 AA Wageningen, The Netherlands.*

Keywords: Laplacian pyramid, multi-temporal data fusion, the Cerrado

ABSTRACT: The Cerrado is the second largest biome in Brazil, covering an area of about 2 million km^2. However, recent estimates revealed that more than one third of the Cerrado was already converted into other land cover types. This paper presents a multi-temporal data fusion experiment where one Landsat TM image (30 m) was fused with a series of MODIS images (250-500 m). Moreover, a simplified data fusion method based on the Laplacian pyramid concept (SIFuLAP) is illustrated. The objective is to assess the ability of the fused images to reflect the seasonal patterns of the Cerrado. In order to do that, NDVI temporal profiles were derived from the fused images and subsequently compared with the ones that were obtained from the original MODIS images. In addition, the temporal fused products were used in an attempt to improve classification accuracy of the Cerrado. The results showed that the NDVI temporal profiles, derived from the fused images, were efficient to assess the seasonal behaviour of the Cerrado. Moreover, classification accuracy was improved using the temporal fused images as additional information into the classifier.

1 INTRODUCTION

The Brazilian savanna, also known as *Cerrado*, is one of the most important biomes of Brazil. Before human disturbance, the Cerrado covered approximately 23% of the total area of the country (around 2 million km^2) and it was the second most important biome after the Amazonian rainforest, which approximately covered 3.5 millions of km^2 (Furley, 1999; Ribeiro and Tabarelli, 2002). However, the area covered by this ancient biome is dramatically decreasing: in 1994 more than one third of the Cerrado was already converted into other land cover types such as annual crops, pastures and eucalyptus plantations (Mantovani and Pereira, 1998; Ferreira et al., 2004). Yet more alarming is a recent study by the Conservation International which indicates, based on an annual rate of deforestation of 1,1%, that the Cerrado may even disappear by the year 2030 (Machado et al., 2004).

The Cerrado has a strong seasonal variation and forms a unique and extremely rich centre of biodiversity estimated to contain approximately 160,000 species of plants, animals and fungi (Eiten, 1993; Ratter et al., 1997; Furley, 1999). Thus, knowledge about the location, spatial distribution and dynamics of the Cerrado patches is crucial to safeguard the biodiversity and the existence of this important biome (Scolforo et al., 2001).

As a vegetation monitoring tool, the temporal profile of the normalized difference vegetation index (NDVI) has been shown to depict seasonal and phenologic activity as well as peak greenness, and onset of greenness in a wide range of environmental conditions (Cihlar et al., 1991; Huete et al., 1999; Wang and Tenhunen, 2004). In the specific case of the Cerrado, França and Setzer (1998) investigated, for a period of 18 months, the temporal pattern of the Cerrado vegetation phenology using 1.1 km full resolution daily images of the Advanced Very High Resolution Radiometer (AVHRR) on-board the NOAA-11 satellite and recommended the use of the 3.7 m band for regular monitoring of the 2×10^6 km^2 of the Cerrado. Ferreira et al (2003), simulated NDVI and EVI vegetation indices for ETM+, MODIS and AVHRR sensors using airborne spectral data acquired by the MODLAND Quick Airborne Looks (MQUALS) package over five cerrado types, and concluded that both indices were found to be linearly correlated with the percent of green cover. The results also suggest that MODIS, or some combination of MODIS and ETM+ (or TM) are sufficient for monitoring seasonal dynamics in the Cerrado.

Combination of information from different sensors to yield a composite image that allows a better understanding of a phenomenon is the aim of data fusion. Generally, fusion techniques are applied for spatial enhancement of multi-spectral images using a single panchromatic (P) band (Wald, 2002; González-Audícana et al., 2005). Fusion of two or more multi-spectral images is also possible though just few studies can be found in the literature (Acerbi-Junior et al., 2005; Oliveira et al., 2005b). Using wavelets as a multi-scale fusion technique, Acerbi-Junior et al (2005) showed that Landsat TM and MODIS images, from the same date, can be fused in order to improve the MODIS classification accuracy to a level comparable to the TM image. Thus, data fusion and multi-scale analysis seems to be a promising approach to integrate information from both sensors: the Landsat TM imagery offers a good spatial resolution needed in fragmented areas of the Cerrado whereas the MODIS sensor is a good mean to capture most of the vegetation dynamics due to its high temporal resolution.

This paper presents a multi-temporal data fusion experiment where one Landsat TM image (30 m) was fused with a series of MODIS images (250-500 m). Moreover, a simplified data fusion method based on the Laplacian pyramid concept (SIFuLAP) is illustrated. The novelty of this method consists in the normalization of the Landsat TM details before they are injected into the different MODIS images. In this way, the radiometric properties of the final product remain as similar as possible to the ones of the coarse resolution image (in this case, MODIS). The objective of the paper is to assess the ability of the fused images to reflect the seasonal patterns of the Cerrado. In order to do that, NDVI temporal profiles were derived from the fused images and subsequently compared with the ones that were obtained from the original MODIS images. In addition, the temporal fused products were used in an attempt to improve classification accuracy of the Cerrado.

2 MATERIAL AND METHODS

2.1 *Study site*

The selected area is located in the State of Minas Gerais and covers approximately 30 by 30 km, from 18°17′ to 18°34′ South latitude and 44°42′ to 44°24′ West longitude. The area represents a complex and fragmented landscape (with cerrado patches, eucalyptus plantations, agricultural plots, gallery forests, grassland and degraded areas), and it is characterized by an average temperature range from 18º to 25º C. The annual precipitation average is from 1000 to 1600 mm and the rainfall is concentrated from October till April (wet season) whereas in the dry season (May through September) the rainfall may be even zero in some months (Oliveira et al., 2005a). Figure 1 shows the strong seasonal patterns in monthly precipitation for the year 2001 as well as the historical data for the last 19 years. The data is an average of the values collected by eight meteorological stations spread around the study region.

2.2 *Remote sensing data and the SIFuLAP method*

The data set was constituted of a Landsat TM image acquired on September 9th, 2001, and of ten MODIS images acquired from January to December 2001 (Table 1). First, the images were geometrically corrected in order to be superimposed. After that, the MODIS bands 1 and 2 were resampled from 250 m to 240 m whereas bands 3, 4, 5, 6, and 7 were resampled from 500 m to

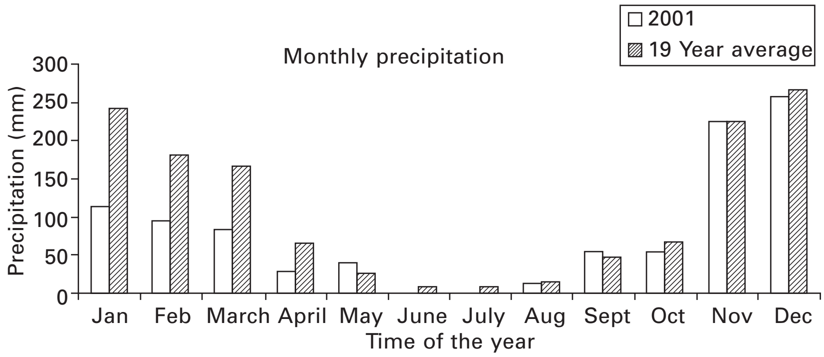

Figure 1. Monthly precipitation pattern for the year 2001, and the average of the last 19 years.

Table 1. Acquisition dates (day/month/year) of the MODIS images used in this study

27/01/2001	10/04/2001	09/06/2001	09/08/2001	27/11/2001
25/03/2001	07/05/2001	15/07/2001	10/09/2001	11/12/2001

480 m using the nearest neighbor resampling algorithm. The Landsat TM and MODIS bands were then fused one by one according to their position in the electromagnetic spectrum. The exception was MODIS band 5 that does not have a Landsat TM band as counterpart at the same wavelength position and was, therefore, fused with the Landsat TM band 5.

The SIFuLAP method is based on the Laplacian pyramid concept. The Laplacian pyramid was first introduced by Burt and Adelson (1983) as a technique of image encoding. The images of a Laplacian pyramid are error images between two levels of the Gaussian pyramid, which is a multi-scale representation obtained through a recursive reduction (i.e., low-pass filtering and decimation). For an extended description of the Laplacian pyramid as well as some applications in data fusion see Burt and Adelson (1983), Aiazzi et al. (1998) and Canga (2002). The main difference of the SIFuLAP method, compared to the original Laplacian pyramid, is the injection of normalized details (Figure 2) so that the radiometric properties of the final product remain as similar as possible to the ones of the original coarse resolution images.

The normalization process consists of two steps:

1. Each Landsat TM detail image is divided by its absolute maximum value so that the range of the detail images is transformed into the interval [–1, 1].
2. These "pre-normalized" detail images are subsequently multiplied at a pixel-based level by their corresponding MODIS expansion images (i.e. images with the same pixel size). In this way, the range of the normalized details is matching the units of the MODIS images.

Let's consider the D3 image as an example:

$$D_{TM}^3 = R_{TM}^2 - E_{TM}^3 \tag{1}$$

$$ND_M^3 = \frac{D_{TM}^3}{\mathrm{Max}|D_{TM}^3|} * E_M^3 \tag{2}$$

$$FX_M^2 = E_M^3 + ND_M^3 \tag{3}$$

During the fusion process, the Landsat TM bands 3 and 4 were decomposed into 3 levels (from 30 to 240 m) whereas bands 1, 2, 5 and 7 were decomposed into 4 levels (from 30 to 480 m). Then, the approximation images were replaced by the corresponding MODIS image and finally the process was inverted (synthesis) in order to reconstruct the fused images (Figure 2).

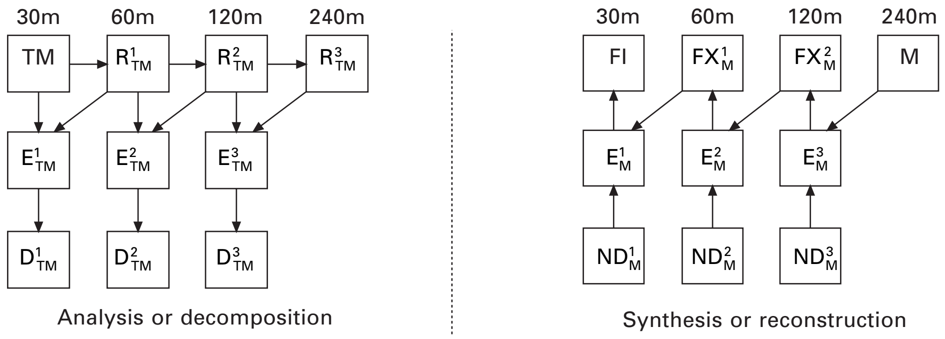

Figure 2. Block representation of the Laplacian pyramid. Where TM is the Landsat image, subscripted TM indicates "coming from Landsat TM"; R^n are the reduction images; E^n are the expansion images; D^n are the detail images; ND^n are the normalized detail images; M is the MODIS image, subscripted M indicates "coming from MODIS"; FX^n are the intermediate fused images and FI is the final fused image.

2.3 *Vegetation seasonal patterns*

To perform a temporal analysis of NDVI values, for three different land cover types: cerrado, eucalyptus plantations and pasture areas, were derived from the ratio of the difference between the fused images bands 1 (RED) and 2 (NIR) to their sum. In order to have a base for comparison, NDVI profiles were also derived from the original MODIS images for the same land cover types.

2.4 *Quality assessment*

Comparison of the fused images with the MODIS image was based on spectral and spatial characteristics and was performed visually and quantitatively using statistical parameters and one quantitative index (Wald et al., 1997; Acerbi-Junior et al., 2004).

First the fused images were downscaled, using the cubic convolution algorithm, to the resolution of the MODIS image. Then, the bias of the mean and the bias of the standard deviation were calculated as the difference between the means and the standard deviations values for the MODIS and the downscaled fused images. After that, the root mean square error (RMSE) between the MODIS images and each downscaled fused image was computed. These parameters allow us to determine the difference in spectral information between each band of the fused image and of the original image(González-Audiícana et al., 2005).

In order to estimate the global spectral quality of the fused images we have used the ERGAS index. The ERGAS index is a relative dimensionless global error index of the fusion process (Wald, 2002):

$$ERGAS = 100\frac{h}{l}\sqrt{\frac{1}{N}\sum_{i=1}^{n}\left(\frac{RMSE^2(B_i)}{M_i^2}\right)} \tag{4}$$

where h is the resolution of the TM image, l is the resolution of the MODIS image, N the number of spectral bands (B_i) involved in the fusion, M_i the mean value of each spectral band and RMSE the root mean square error. The lower the ERGAS value the higher the spectral quality of the fused images.

2.5 *Classification*

Since post-processing techniques like classification are based on the spectral information of the images they can also be used in order to assess the quality of the fused images (Acerbi-Junior et al., 2005). Classification of the Landsat TM and of the fused images was performed by using the maximum likelihood algorithm, as it is the most popular for classification of remote sensing imagery (Carvalho et al., 2004). It calculates the probability of membership in each class using the classes' mean feature vector, covariance matrix and prior probability. The unknown pixel is considered to belong to the class with maximum probability of membership.

The classifier was trained with a set of 4460 pixels of 30 by 30 m distributed over 7 classes and the accuracy was assessed using an independent validation set of 4561 pixels (Table 2). Both data sets were generated using a stratified random distribution of pixels (Congalton and Green, 1999), resulting in approximately equal set sizes. Training and validation sets were obtained during field and aerial campaigns in 2002 and 2003. For classification comparisons the overall accuracy as well as the *kappa* and 'per class' accuracy measures were used.

Table 2. Distribution of the number of pixels among the classes for the training and validation sets

Class	Training set	Validation set
Water	91	92
Bare soil	666	670
Annual crops	104	108
Eucalyptus	1222	1292
Pasture	1060	1069
Cerrado	883	886
Forest	434	444
Total	4460	4561

3 RESULTS AND DISCUSSION

3.1 *Quality assessment*

All fused images presented small bias of the mean for all bands and slightly higher bias of the standard deviation, mainly for bands 5 and 6. The explanation for that is probably the fact that MODIS band 5 does not have a Landsat TM band as counterpart at the same wavelength position. Since all fused images present a similar trend, Figure 3 shows the bias of the mean and the bias of the standard deviation only for the fused image on 9th of June 2001.

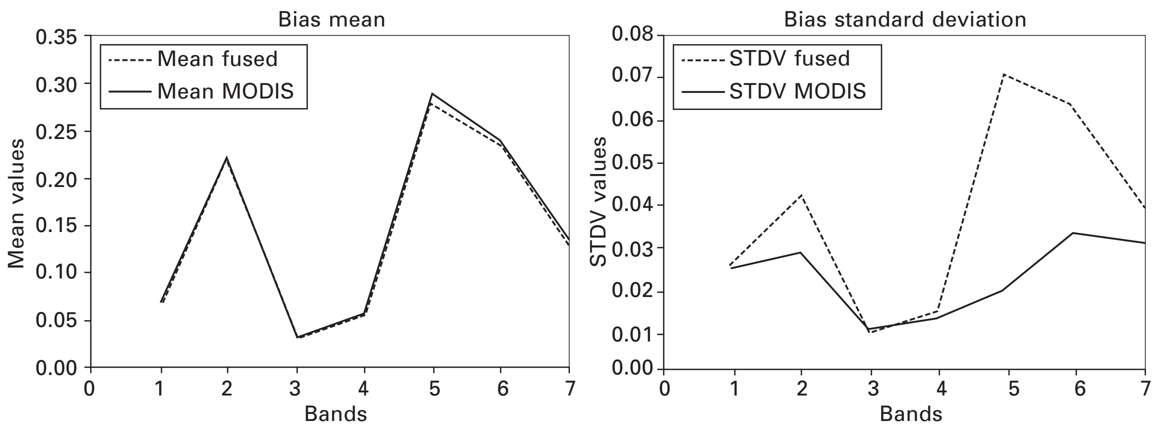

Figure 3. Bias of the mean and of the standard deviation between the MODIS and the fused images.

The root mean square error (RMSE) and the ERGAS index are presented in Table 3. According to Wald (2002), ERGAS values equal or lower than 3 indicate that the global error is small and therefore the fused product is of good quality. If the ERGAS values are well above 3, the global error is large and the product is of lower quality. All fused images presented values higher than 3, the only exception was the fused image from September: ERGAS = 2.28. As the TM image was also acquired on September it was expected a better performance on this date, however, the ERGAS values for the images on different dates are not far from 3, which lead us to considering them as from good to medium quality. The fused image of January presented the highest ERGAS value and the reason for that could be not only the time gap with the TM image but also the fact that this was the only image which was partially clouded.

Table 3. RMSE (absolute values) for each band and the relative global spectral error index (ERGAS)

Bands	Statistics	Jan	March	April	May	June	July	Aug	Sept	Nov	Dec
1	RMSE	0.027	0.031	0.030	0.026	0.024	0.031	0.033	0.033	0.034	0.026
2	RMSE	0.051	0.048	0.045	0.045	0.038	0.038	0.040	0.041	0.049	0.044
3	RMSE	0.011	0.011	0.010	0.009	0.013	0.010	0.011	0.012	0.014	0.010
4	RMSE	0.019	0.019	0.019	0.017	0.017	0.019	0.021	0.020	0.022	0.017
5	RMSE	0.086	0.085	0.085	0.088	0.072	0.085	0.089	0.090	0.086	0.075
6	RMSE	0.066	0.071	0.072	0.074	0.064	0.078	0.086	0.084	0.077	0.063
7	RMSE	0.043	0.048	0.048	0.046	0.041	0.055	0.061	0.058	0.055	0.044
	ERGAS	4.249	3.763	3.729	3.528	3.721	3.441	3.299	2.280	3.673	3.706

3.2 *Vegetation seasonal patterns*

The seasonal behaviour of the Cerrado is clearly seen in the NDVI temporal profile (Figure 4). High NDVI values, indicative of high photosynthetic activity and biomass accumulation are found in the rainy months, while the lowest values were encountered in the dry period (see Figure 1 with the monthly precipitation). These results are in total agreement with other phenologic studies of the Cerrado vegetation carried out in different regions of Brazil (França and Setzer, 1998; Ferreira et al., 2004). Pastures areas showed an earlier senescence and the largest variation in NDVI, which is typical of this type of vegetation (Ferreira and Huete, 2004). The eucalyptus plantations, which are evergreen during the whole season, showed the highest NDVI values and the smallest variation. Figure 4 shows also the NDVI temporal profiles derived from the original MODIS images, which is very similar to those encountered in the fused images. The advantage of the fused products is that "new" areas of the Cerrado, which are not visible due to the MODIS coarse spatial resolution, can now be assessed.

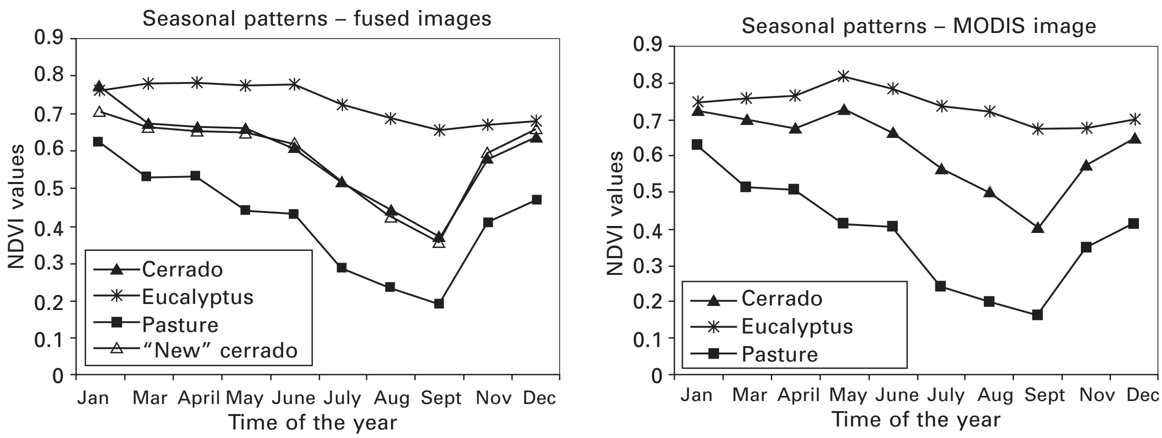

Figure 4. NDVI temporal profiles of the cerrado, eucalyptus plantations and pastures areas from fused images as well as from the original MODIS image.

3.3 *Classification*

The classification process depends on the spectral information and any error in the synthesis of the spectral content of the fused image will result in classification errors (Meenakshisundaram and Couloigner, 2004).

We used the classes presented in Table 2, but report only the most important one: the cerrado. The overall accuracy, the kappa coefficients and the cerrado-class accuracies are presented in Table 4 for the Landsat TM image and for the fused images plus the NDVI temporal profiles. In terms of overall accuracy and kappa coefficient the fused images plus the NDVI temporal profiles showed higher values compared to the Landsat TM image. A similar trend was observed considering the specific case of mapping the cerrado class; the fused product showed values around 5% higher for producer's accuracy and around 2.5% higher for user's accuracy. The results showed that the temporal profiles are important for a better discrimination of the Cerrado. Indeed, in the Landsat TM image around 7.5% of the cerrado pixels were misclassified as some type of forest (natural forest or eucalyptus plantations), while in the fused product only 4% of the cerrado pixels were misclassified as other type of forest.

Table 4. Accuracy measures for the cerrado map produced from the Landsat TM image from the fused images

Cerrado Class	Landsat TM	Fused plus NDVI profiles
Commission errors (%)	9.61	7.20
Omission errors (%)	10.56	5.80
Producer's accuracy (%)	89.44	94.20
User's accuracy (%)	90.39	92.80
Overall accuracy (%)	87.59	94.08
Kappa coefficient	0.84	0.92

4 CONCLUSIONS

A multi-temporal data fusion experiment using one single Landsat TM image and a series of ten MODIS images (covering the phenological cycle of the Cerrado) has been presented in this paper. The possibilities of using a NDVI temporal profile based on the fused images for monitoring the seasonal behaviour of the cerrado – with a high temporal and spatial resolution – were also evaluated. Results pointed out that there was a close relationship between the NDVI temporal profile based on the fused images and the precipitation regime of the area, which in turn is the main driver of the temporal dynamics of the Cerrado. Additionally, this NDVI temporal profile was very similar to the one derived from the original MODIS images, indicating the radiometric properties of MODIS were preserved. From these findings, we conclude that NDVI temporal profiles based on fused images can be used to monitor the seasonal variation of the Cerrado. Finally, a maximum likelihood classification rule was applied to the series of fused and NDVI images, resulting in an improved overall classification accuracy, and most important, in an increase of the classification accuracy for the class Cerrado.

The SIFuLAP method was successful in performing the multi-temporal data fusion. The radiometric properties of MODIS (mean reflectance of each band) were well preserved during the data fusion process. The ERGAS value for the fused image of September 2001 (which is just one day apart from the date of the Landsat TM) was of 2.28, whereas for the rest of the fused images the ERGAS values were shortly above the empiric threshold of 3, which characterized the fused images as from good to medium quality. Nevertheless, the SIFuLAP method has proved to be very simple and computationally efficient since there is no need for any pre-processing of the images (e.g. no histogram equalisation is required).

ACKNOWLEDGEMENTS

CNPq (Conselho Nacional de Desenvolvimento Científico e Technológico) from Brazil is acknowledged for funding this research through a PhD fellowship for the principal author.

REFERENCES

Acerbi-Junior, F.W., Carvalho, L.M.T., Wachowicz, M. and Clevers, J.G.P.W. 2004. Are we using the right quality measures in multi-resolution data fusion? Proceedings of the 24th EARSeL Symposium “New Strategies for European Remote Sensing”, Millpress. Dubrovnik, Croatia: pp. 361-368.

Acerbi-Junior, F.W., Clevers, J.G.P.W. and Schaepman, M.E. 2005. Multi-sensor image fusion using wavelet transforms for classification of the Brazilian Cerrado. *International Journal of Applied Earth Observation and Geoinformation* (submitted).

Aiazzi, B., Alparone, L. and Baronti, S. 1998. Multiresolution local-statistics speckle filtering based on a ratio laplacian pyramid. *IEEE Transactions on Geoscience and Remote Sensing* 36 (5): 1466-1476.

Burt, J.P. and Adelson, E.H. 1983. The Laplacian Pyramid as a Compact Image Code. *IEEE Transactions on Communications* 31: 532-540.

Canga, E.F. 2002. Image Fusion. Departament of Electronic & Electrical Engineering. University of Bath, Bath: 72 p.

Carvalho, L.M.T., Clevers, J.G.P.W., Skidmore, A.K. and De Jong, S.M. 2004. Selection of imagery data and classifiers for mapping Brazilian semideciduous Atlantic forests. *International Journal of Applied Earth Observation and Geoinformation* 5 (3): 173-186.

Cihlar, J., St.-Laurent, L. and Dyer, J.A. 1991. Relation between the normalized difference vegetation index and ecological variables. *Remote Sensing of Environment* 35 (2-3): 279-298.

Congalton, R.G. and Green, K. 1999. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. Lewis Publishers, Boca Raton. Florida, 137 p.

Eiten, G. 1993. Cerrado’s vegetation. M.N. Pinto (Editor), Cerrado: Caracterização, ocupação, e perspectivas. Universidade de Brasília. Brasília, DF - Brazil: 17-73.

Ferreira, L.G. and Huete, A.R. 2004. Assessing the seasonal dynamics of the Brazilian Cerrado vegetation through the use of spectral vegetation indices. *International Journal of Remote Sensing* 25 (10): 1837-1860.

Ferreira, L.G., Yoshioka, H., Huete, A. and Sano, E.E. 2003. Seasonal landscape and spectral vegetation index dynamics in the Brazilian Cerrado: An analysis within the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA). *Remote Sensing of Environment* 87 (4): 534-550.

Ferreira, L.G., Yoshioka, H., Huete, A. and Sano, E.E. 2004. Optical characterization of the Brazilian Savanna physiognomies for improved land cover monitoring of the cerrado biome: preliminary assessments from an airborne campaign over an LBA core site. *Journal of Arid Environments* 56 (3): 425-447.

França, H. and Setzer, A.W. 1998. AVHRR temporal analysis of a savanna site in Brazil. *International Journal of Remote Sensing* 19 (16): 3127-3140.

Furley, P.A. 1999. The nature and diversity of neotropical savanna vegetation with particular reference to the Brazilian cerrados. *Global Ecol Biogeography* 8 (3-4): 223-241.

González-Audícana, M., Otazu, X., Fors, O. and Seco, A. 2005. Comparison between Mallat’s and the ‘à trous’ discrete wavelet transform based algorithms for the fusion of multispectral and panchromatic images. *International Journal of Remote Sensing* 26 (3): 595-614.

Huete, A., Justice, C. and van Leeuwen, W. 1999. Modis vegetation index (Mod 13). Algorithm theoretical basis document (version 3). 122 p.

Machado, R.B., Ramos Neto, M.B., Pereira, P.G.P., Caldas, E.F., Gonçalves, D.A., Santos, N.S., Tabor, K. and Steininger, M. 2004. Estimativas de perda da área do Cerrado brasileiro. Relatório técnico não publicado. Conservação International. Brasília, DF: 23p.

Mantovani, J.E. and Pereira, A. 1998. Estimativa da integridade da cobertura vegetal de cerrado através de dados TM/Landsat. Simpósio Brasileiro de Sensoriamento Remoto. Santos, Brazil, 9: 1-8.

Meenakshisundaram, V. and Couloigner, I. 2004. Image fusion of Ikonos pan and multispectral images for classification of the urban environment. Proceedings of the 24th EARSeL Symposium “New Strategies for European Remote Sensing”, Millpress. Dubrovnik, Croatia: pp. 335-342.

Oliveira, L.T., Carvalho, L.M.T. and Acerbi-Junior, F.W. 2005a. Mineração de dados geográficos para mapear as fitofisionomias do bioma cerrado. Anais XII Simpósio Brasileiro de Sensoriamento Remoto, INPE. Goiânia, Brasil: p. 4177-4184.

Oliveira, L.T., Carvalho, L.M.T. and Acerbi-Junior, F.W. 2005b. Seleção de métodos para aumentar a resolução de imagens dos sensores ETM+ e ASTER por meio de fusão de imagens. Anais XII Simpósio Brasileiro de Sensoriamento Remoto, INPE. Goiânia, Brasil: p. 4185-4192.

Ratter, J.A., Ribeiro, J.F. and Bridgewater, S. 1997. The Brazilian Cerrado Vegetation and Threats to its Biodiversity. *Annals of Botany* 80: 223-230.

Ribeiro, L.F. and Tabarelli, M. 2002. A structural gradient in cerrado vegetation of Brazil: changes in woody plant density, species richness, life history and plant composition. *Journal of Tropical Ecology* 18: 775-794.

Scolforo, J.R.S., Oliveira, A.D., Mello, J.M., Acerbi-Junior, F.W., Borges, L.F.R. and Oliveira, L.T. 2001. O manejo de fragmentos nativos, na Vallourec & Mannesmann Florestal, região de Curvelo, Minas Gerais. Universidade Federal de Lavras – UFLA. Lavras, Brasil: 305 p.

Wald, L. 2002. Data Fusion Definitions and Architectures: Fusion of images of different spatial resolutions. École des Mines de Paris. Paris, 198 p.

Wald, L., Ranchin, T. and Mangolini, M. 1997. Fusion of sattelite images of different spatial resolutions: assessing the quality of resulting images. *Photogrammetric Engineering & Remote Sensing* 63 (6): 691-699.

Wang, Q. and Tenhunen, J.D. 2004. Vegetation mapping with multitemporal NDVI in North Eastern China Transect (NECT). *International Journal of Applied Earth Observation and Geoinformation* 6 (1): 17-31.